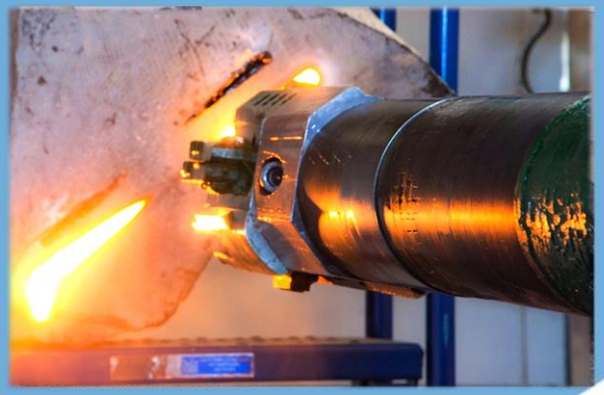
arpa·e
CHANGING WHAT'S POSSIBLE



Patrick McGrath
Associate Director for Technology

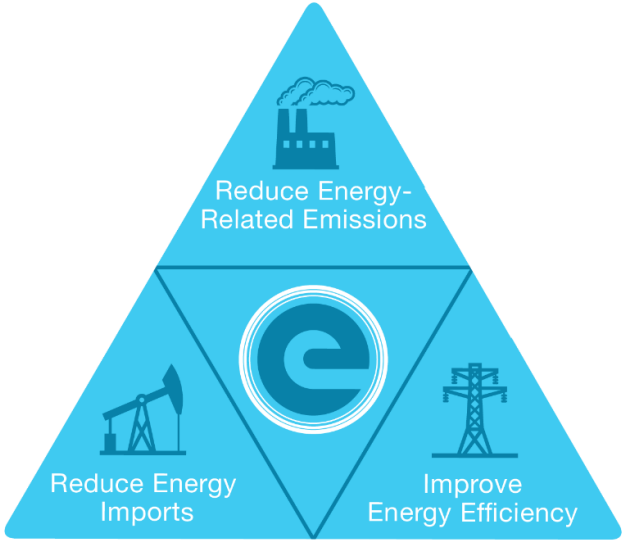
http://www.arpa-e.energy.gov/

Introduction to ARPA-E

Mission: To overcome long-term and high-risk technological barriers in the development of energy technologies

Goals: Ensure America's

- Economic Security
- Energy Security
- Technological Lead in Advanced Energy Technologies

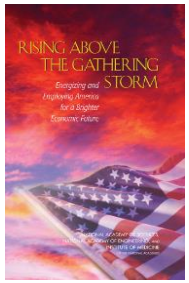


Means:

- Identify and promote revolutionary advances in fundamental and applied sciences
- Translate scientific discoveries and cutting-edge inventions into technological innovations
- Accelerate transformational technological advances in areas that industry by itself is not likely to undertake because of technical and financial uncertainty

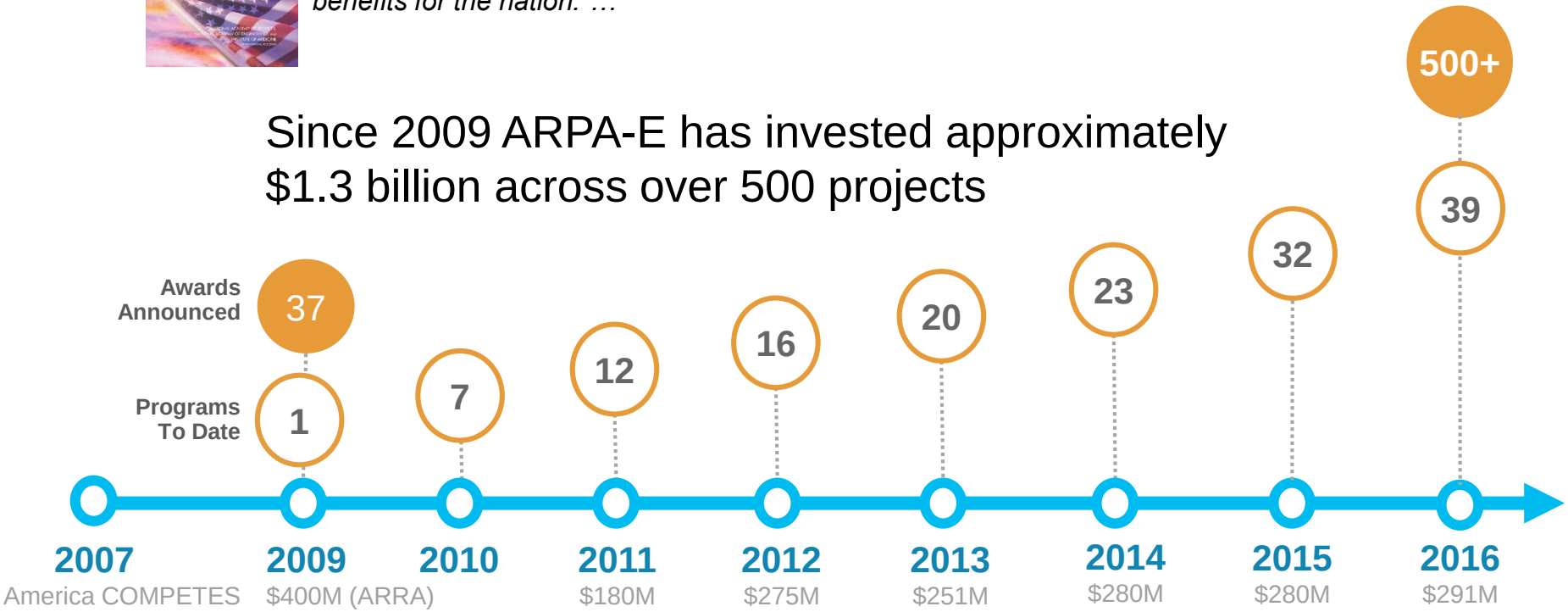
A Brief History of ARPA-E

In 2007, The National Academies recommended Congress establish an Advanced Research Projects Agency within the U.S. Department of Energy

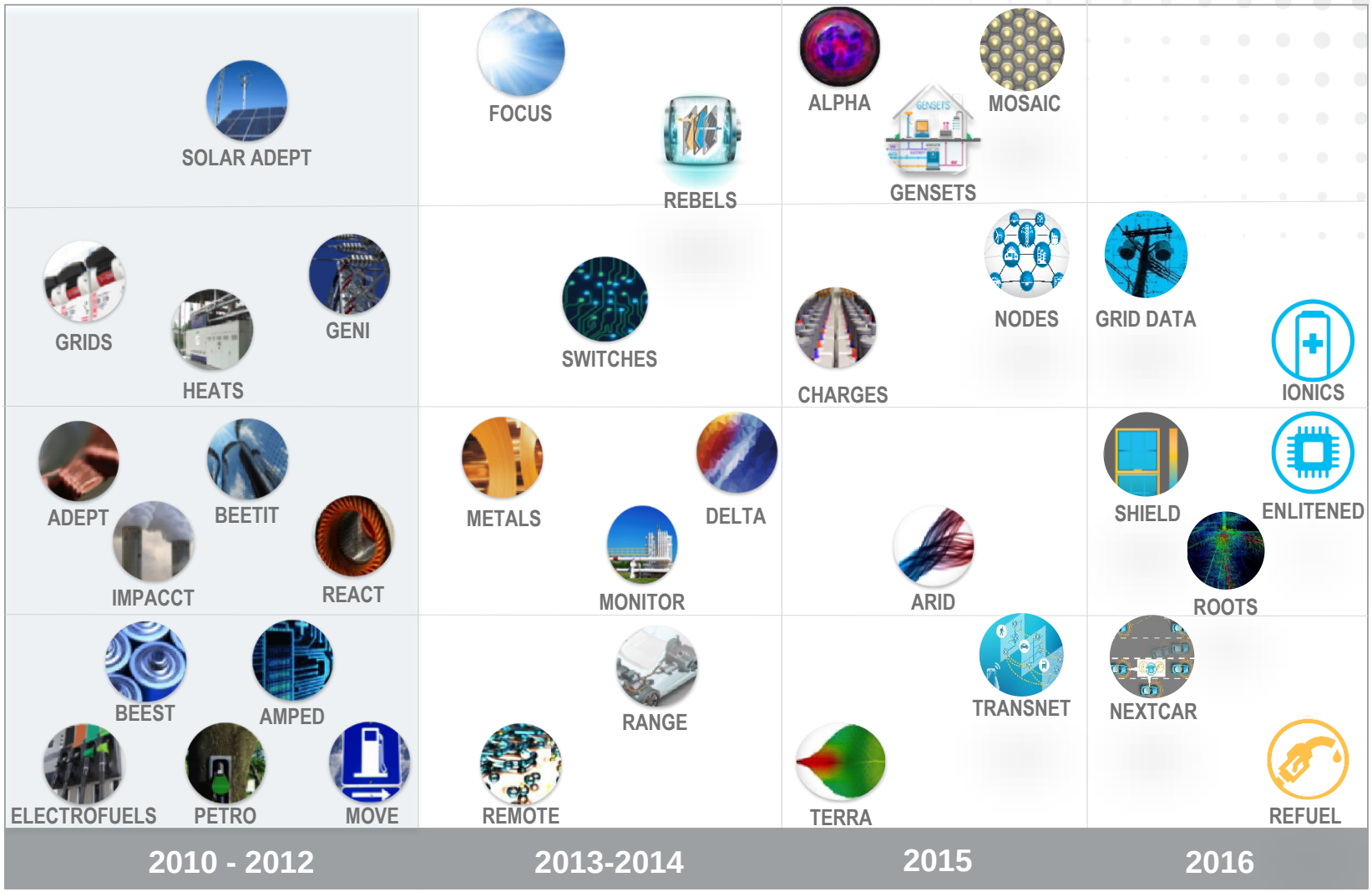


…"The new agency proposed herein [ARPA-E] is patterned after that model [of DARPA] and would sponsor creative, out-of-the-box, transformational, generic energy research in those areas where industry by itself cannot or will not undertake such sponsorship, where risks and potential payoffs are high, and where success could provide dramatic benefits for the nation."…

Since 2009 ARPA-E has invested approximately $1.3 billion across over 500 projects

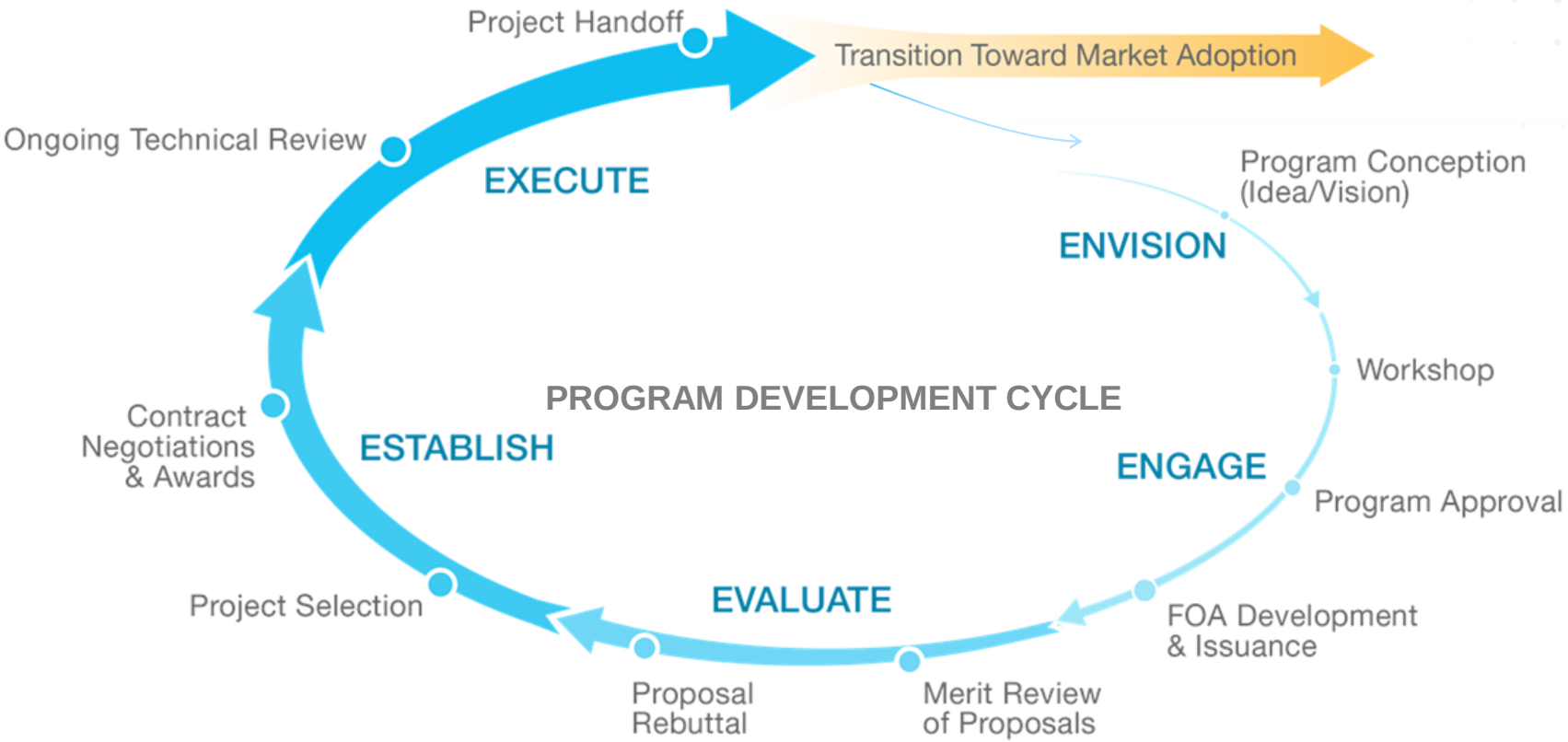


Program Portfolio



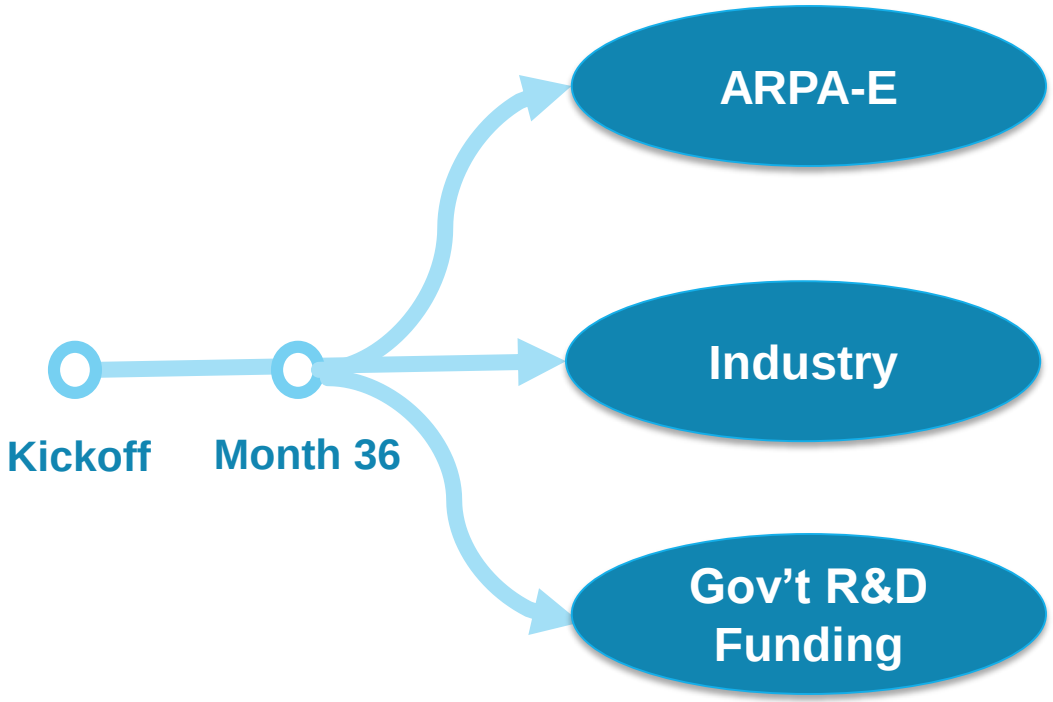
Developing ARPA-E Focused Programs

ARPA-E Program Directors



Technology to Market (T2M)

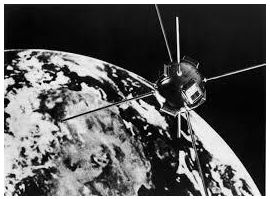
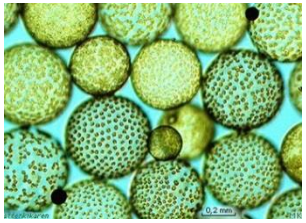
- What happens to this project when the funding runs out?



Why month 37 matters so much

- **Return on the public dollar** – publishing is great, but we're here to move a market
- **Momentum –** Teams have clear view on what's required next
- **Team** – maintain institutional knowledge
- **Thought leadership** – Validate that we've hit upon an idea that really matters

T2M: Realizing the full potential of technology is long process

Technology	First market	Intermediate Markets	Market disrupted
Li-Ion Batteries 	 Long lived, energy dense cells	 Long lived, energy dense, rechargeable	 Long lived, energy dense, rechargeable, cost-effective
Photovoltaics 			
Biofuels 	 Nutrition supplements, pharmaceuticals	 	Commodity fuels? 

Decreasing cost →

Measuring ARPA-E's Success

Since 2009 ARPA-E has invested approximately $1.3 billion across over 500 projects, through 32 focused programs and 3 open funding solicitations.

For all alumni and current projects:

- Follow-on Funding
  - 45 projects have attracted more than $1.25 billion from the private sector
- Partnerships with other government agencies
  - 60 government projects
- New company formation
  - 36 new companies formed

Want to work at ARPA-E?
There may be a role for you!

Program Director

- Program development
- Active project management
- Thought leadership
- Explore new technical areas

Technology-to-Market Advisor

- Business development
- Technical marketing
- Techno-economic analyses
- Stakeholder outreach

Fellow

- Independent energy technology development
- Program Director support
- Organizational support

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If you are interested in applying or learning more, please email arpa-e-jobs@hq.doe.gov

ARPA-E METALS ANNUAL MEETING

Welcome and Introduction

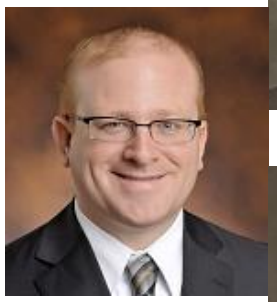
Renaissance Center
Detroit, MI

Osaka Titanium Technologies

METALS ARPA-E Team

- Patrick McGrath Program Director
- Paul Albertus Program Director
- Jason Rugolo Program Director
- Tim Heidel Program Director
- Chris Atkinson Program Director
- Eric Schiff Program Director



METALS ARPA-E Team

- Grigorii Soloveichik Program Director
- JC Zhao Program Director
- Dawson Cagle Technical Support
- Gokul Vishwanathan Technical Support
- Bahman Abbasi Technical Support
- Patrick Finch Tech-to-Market Support





ARPA-E METALS Program

Vehicle Lightweighting is the Future

4 Quads energy savings potential in fuel economy

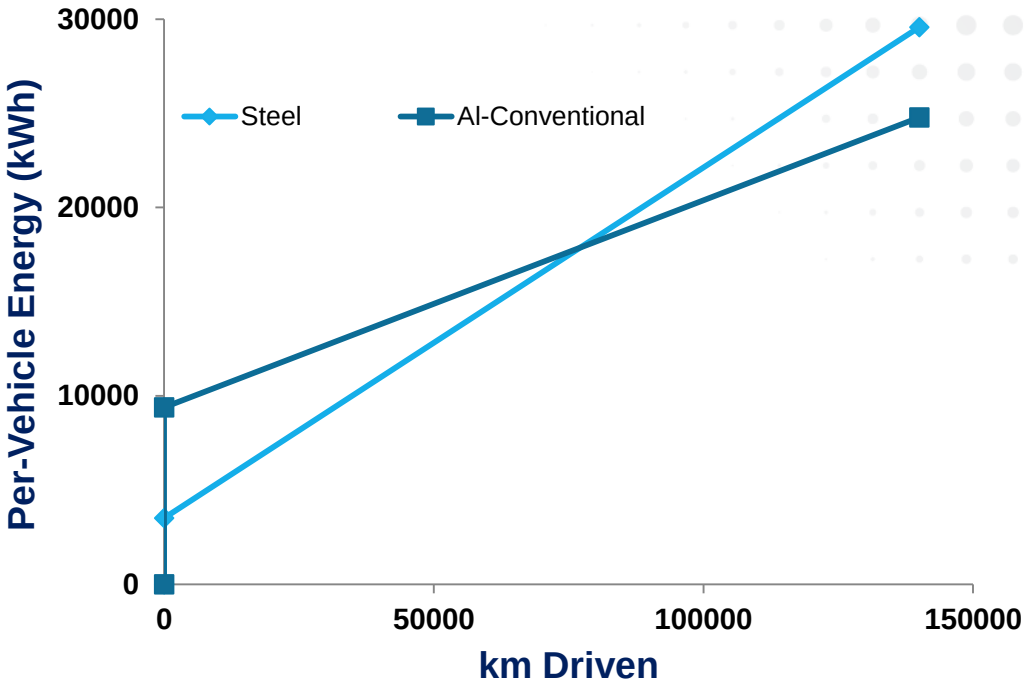
Lightweight: 26 mpg
(40% improvement over steel)

30% less fuel consumption

Global Demand for Aluminum, Magnesium and Titanium Projected to More than Double by 2025

Challenges for vehicle lightweighting

Higher energy, cost, and emissions in light metal production compared with steel



	Energy kWhr/kg	Emissions kg_{CO2}/kg
Steel	6.4	2.3
Al	56	22
Mg	44	7

METALS Programmatic Objectives

Primary Light Metal Production

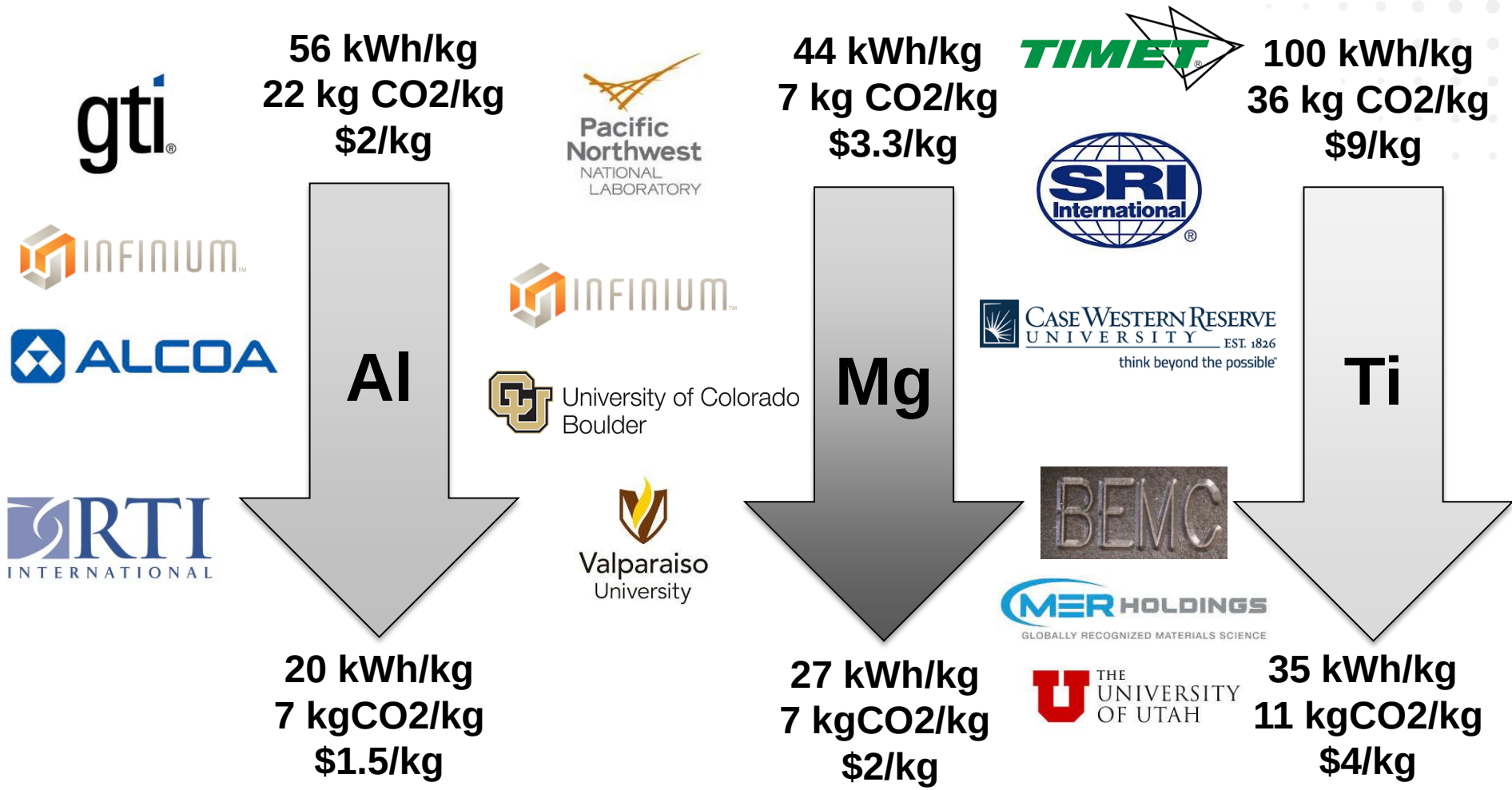
Reduce the energy, emissions, and cost so that Al and Mg reach parity with steel and Ti reaches parity with stainless steel

Secondary Light Metal Production

Develop a suite of advanced diagnostic technologies to enable the domestic segregation and reuse of all light metal scrap material

ARPA-E METALS Program

Primary Metal Production



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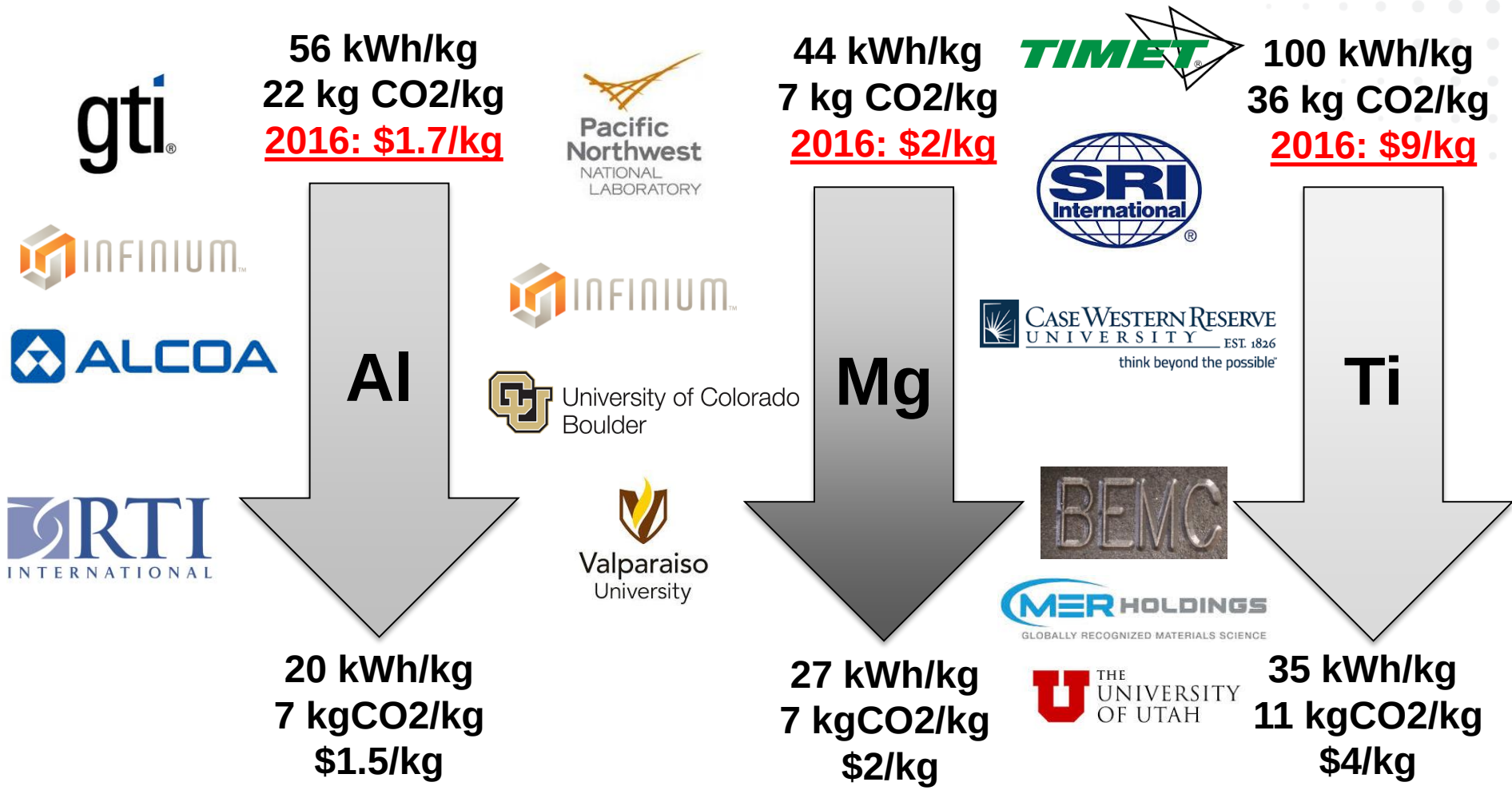
Steel Parity

Steel Parity

S Steel Parity

ARPA-E METALS Program

Primary Metal Production



Steel Parity

Steel Parity

S Steel Parity

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METALS program in 2016

Since the launch of the METALS program, commodity prices have plummeted…

Commodity Al, Mg, and Ti:

Glut pricing a major challenge to new technologies

But some niche industries could provide high value-added markets…

High quality metal powders

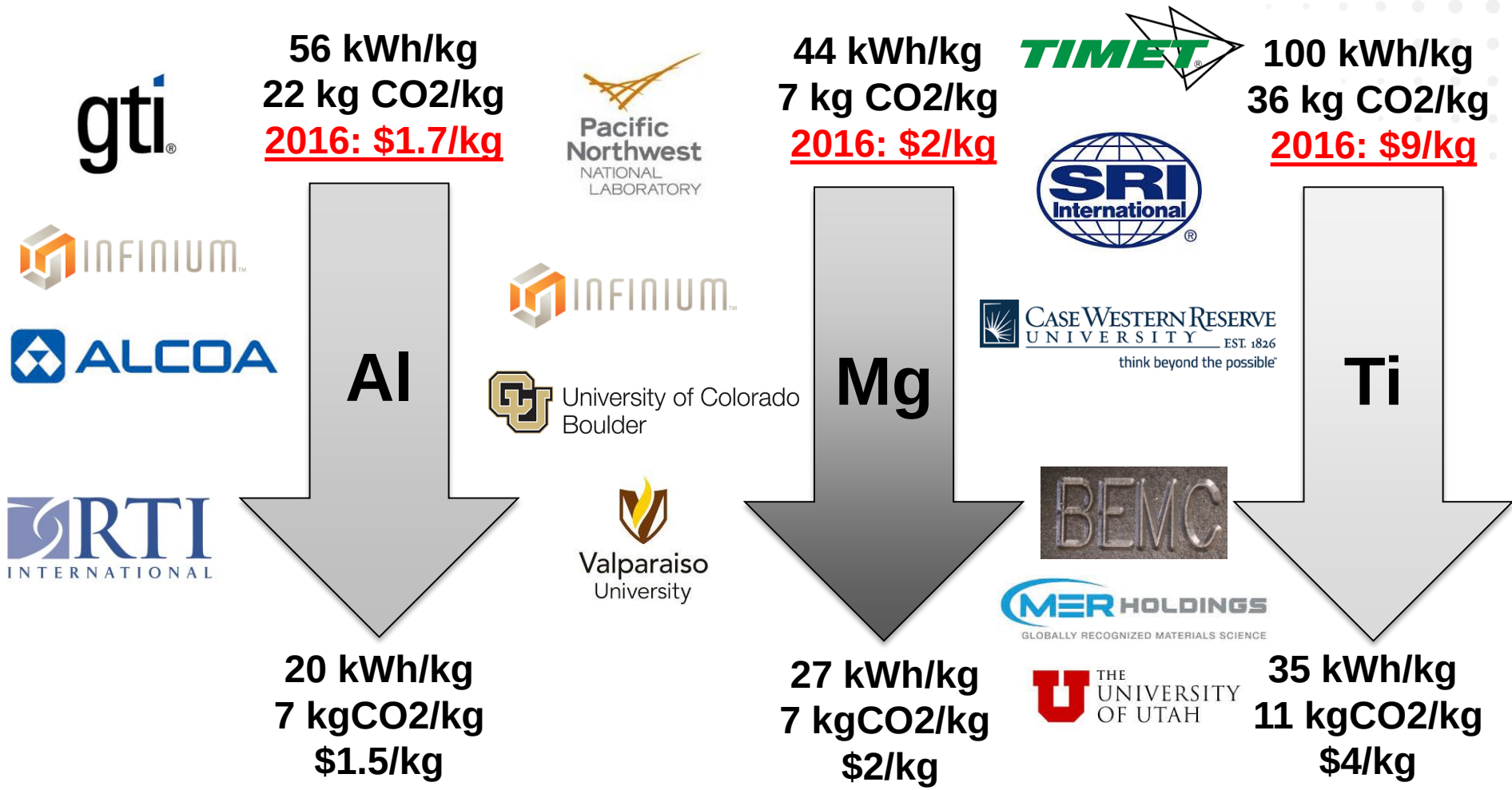
Custom Alloy Parts

Materials for 3D Printing

… and allow new technologies to commercialize.

ARPA-E METALS Program

Primary Metal Production



Steel Parity

Steel Parity

S Steel Parity

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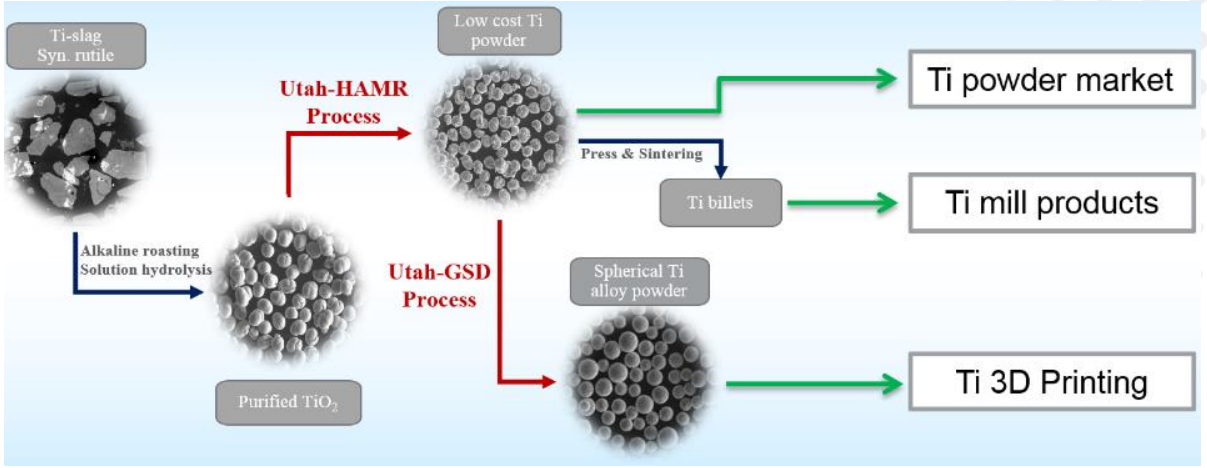
Primary Production of Titanium

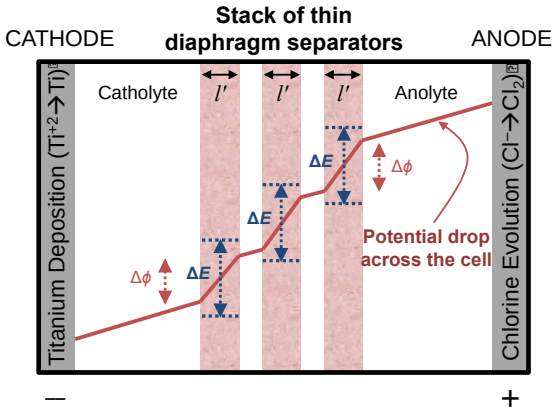
THE UNIVERSITY OF UTAH

Acid leaching of Ti slag and MgH_2 reduction for Ti powder production



CASE WESTERN RESERVE UNIVERSITY EST. 1826
think beyond the possible

Electrowinning of $TiCl_4$ to Ti powder using segmented thin diffusion barriers to prevent bipolarity.



Criterion for elimination of diaphragm bipolarity:

Ohmic Potential Drop ($\Delta\phi$) $= il'/\kappa <$ Equilibrium Potential for Bipolar Reactions (ΔE)

Thus, we propose using multiple thin (small l') diaphragms

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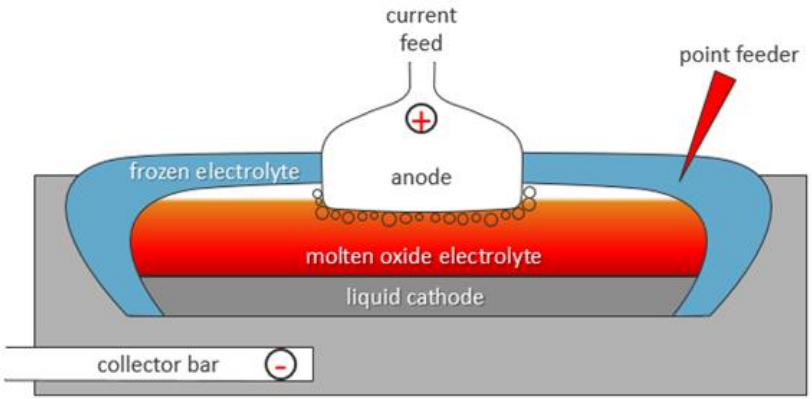
Primary Production of Titanium

MER HOLDINGS
GLOBALLY RECOGNIZED MATERIALS SCIENCE

Hybrid ilmenite carbothermic/electrolysis reduction for Ti direct powder production

BEMC

Titanium at the cost of stainless steel.
A new electrolytic process for extracting titanium from ore feedstocks that are currently unusable.

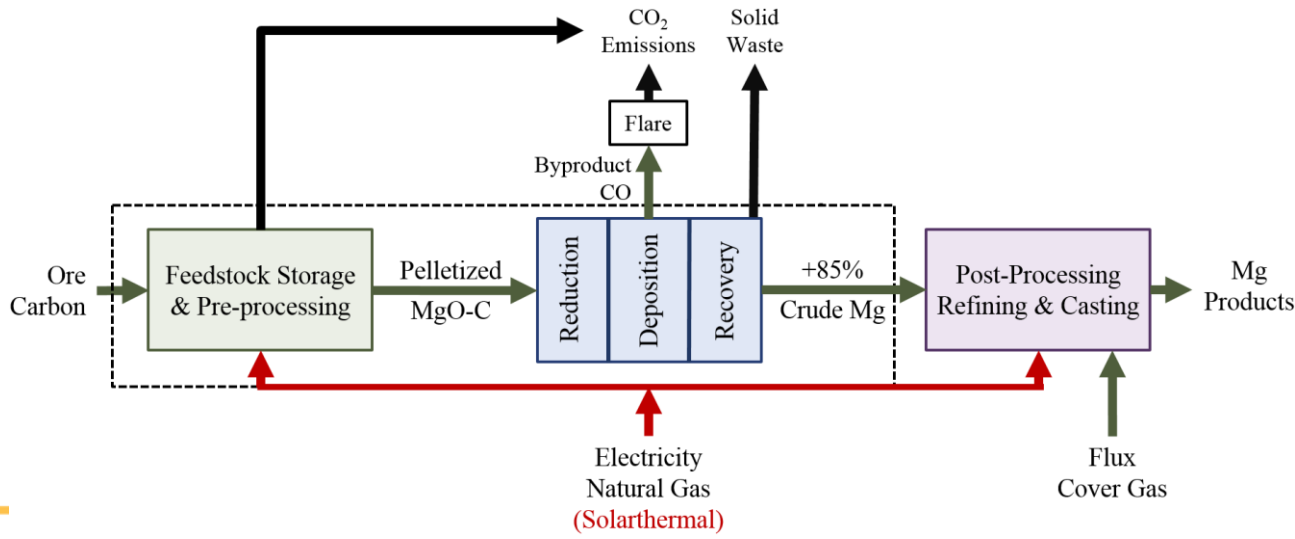


Primary Production of Magnesium

Valparaiso University

Hybrid electrochemical/ solar thermal reduction of MgO using hydrodynamic separation

Carbothermic reduction of MgO using falling particle reactor and particle seeding for separation



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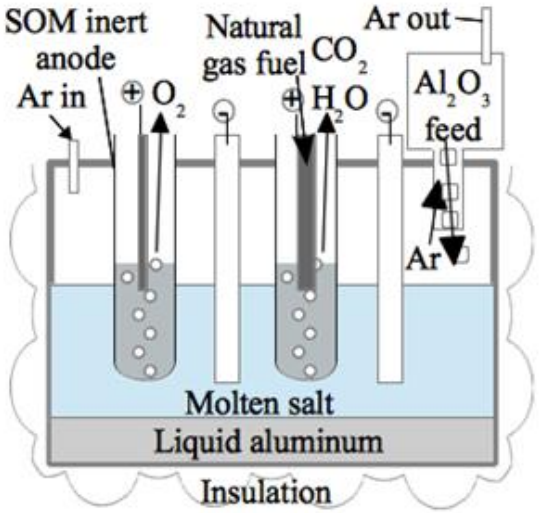
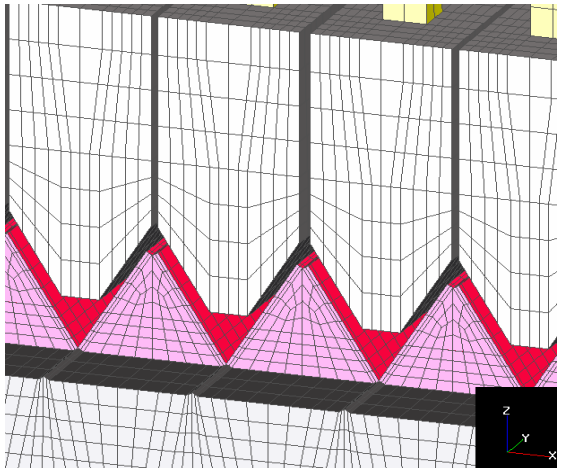
Primary Production of Aluminum

Direct electrowinning of Aluminum/Scandium Alloy for aerospace application at substantial reduced cost.

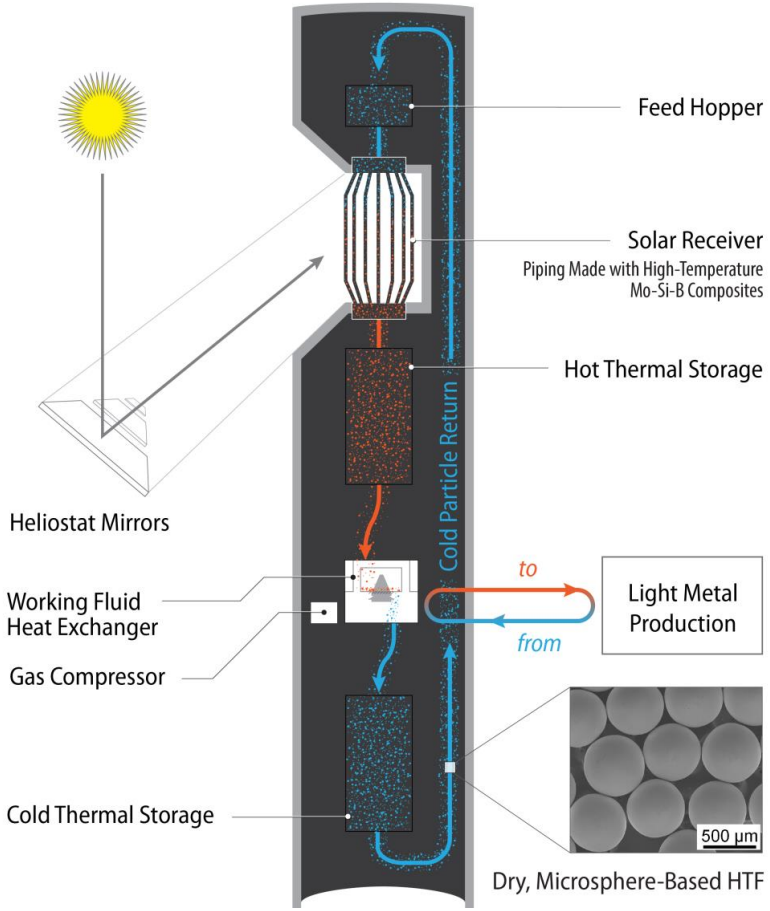


Sloped cathode Hall cell with thermal energy recovery at pilot scale of 65kA.



Thermal Energy Transfer

High temperature thermal energy storage using flowing ceramic powder



ARPA-E METALS Program: Recycling

Auto Scrap

Non-Ferrous Concentrate "Zorba"

Light Metal Alloy "Twitch"

High Grade
Al 5000/6000 Alloy

Zinc, Copper, Bronze, Stainless "Zebra"

Low Grade
Al 300 Alloy

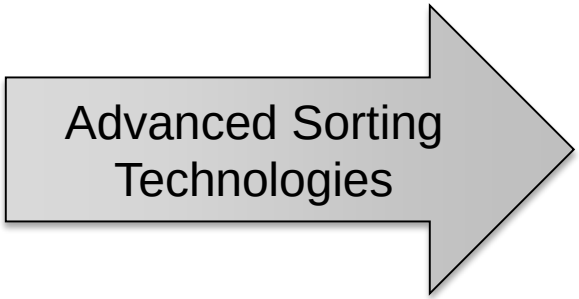
Ferrous Scrap

Steel Minimill

- The United States aggregates over 5.45 MT of Al scrap annually
- Over 1/3 of this scrap is exported, representing > 111,000 GWh of energy, (~3% of the total U.S. annual electricity generation)
- These exports are sold at ~$1,568 million less than the intrinsic value of the metal (because scrap is mixed alloys)

ARPA-E METALS Program

Secondary Metal Production

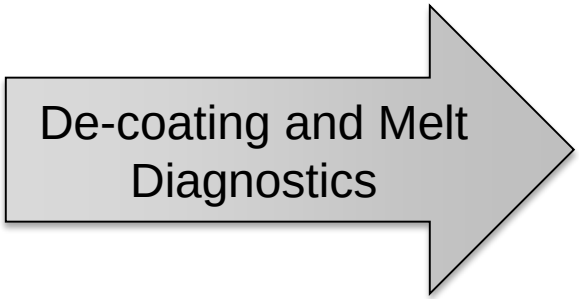


BlazeTech

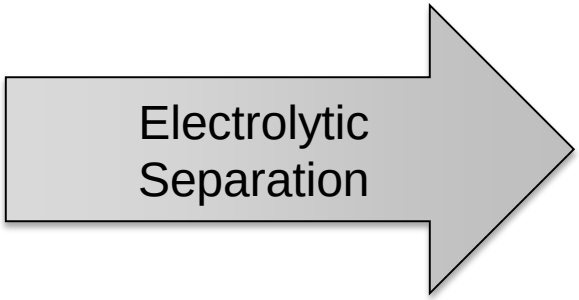
parc
Palo Alto Research Center

UHV Technologies, Inc.

THE UNIVERSITY OF UTAH



ERCo ENERGY RESEARCH COMPANY

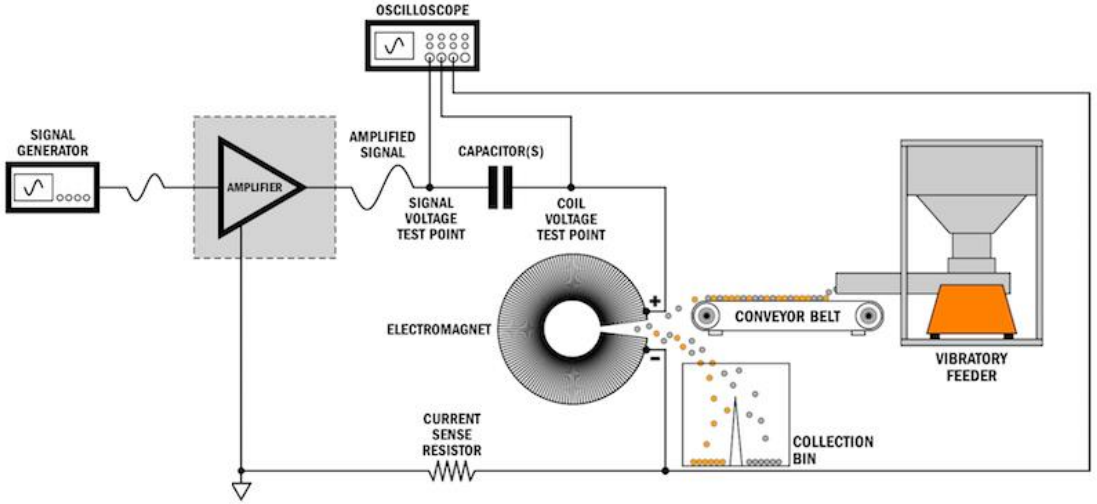


PHINIX LLC
Globally Responsible Resource Management

Recycling Technologies

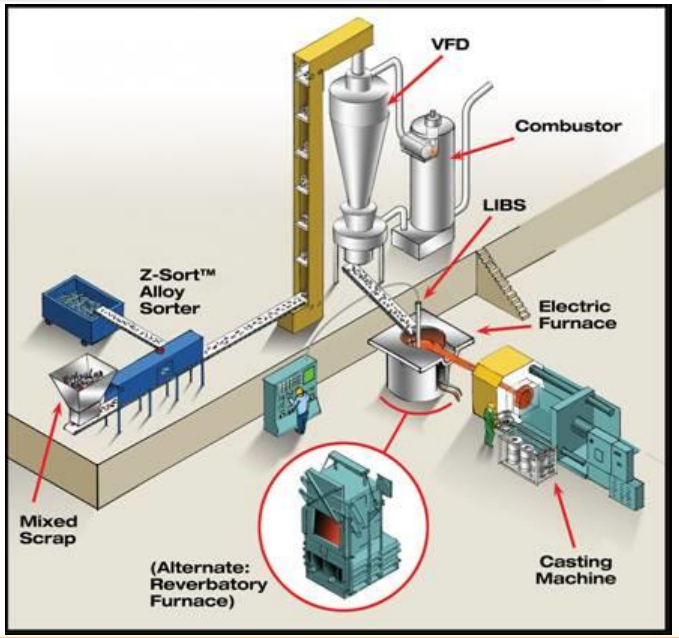
THE UNIVERSITY OF UTAH

Variable frequency electrodynamic sorting machine



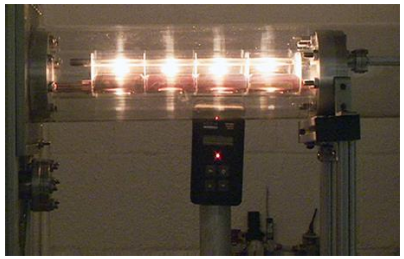
ERCo

Integrated Al minimill; sorting, decoating, composition analysis and casting



Recycling Technologies

UHV Technologies, Inc.

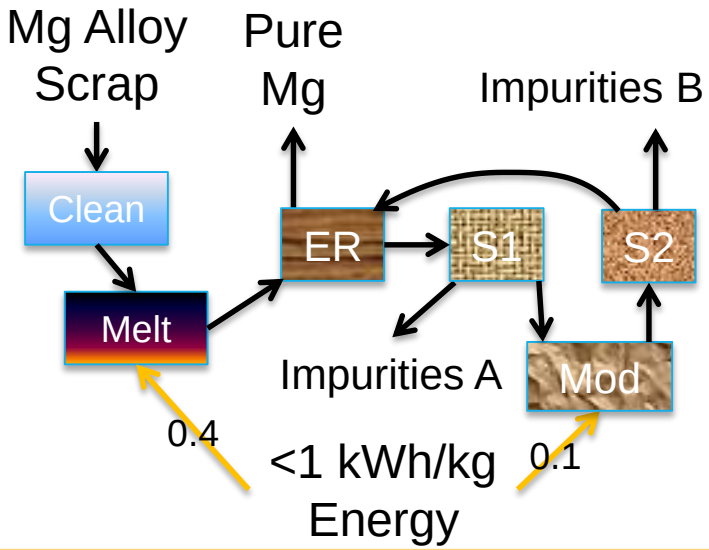


- 5 kW Linear X-Ray Tube
- Worlds most powerful industrial x-ray source

X-ray scrap metal sorter

INFINIUM

Develop a low-cost process for refining mixed magnesium alloy scrap into pure (99.9%+) magnesium using less than 1 kWh/kg product



METALS Program Highlights

- Successfully demonstrated of ore-to-metal production of Al, Mg, Ti
- Successfully demonstrated of scrap sorting capabilities
- *All of the projects presented at this meeting have a viable pathway for commercial success*

Meeting Objectives

- Highlight challenges and opportunities for scale-up of light metals production and reuse technologies
- Showcase technical breakthroughs and illustrate future value to the industry
- Promote networking within the technical community to increase collaboration
- Project the future state of the industry and identify technology needs

Meeting Agenda – Day 1

	Agenda	Objective
9:00-9:30	Welcome and introduction to the program	• Program goals and targets • Introduction to the portfolio
9:30-10:30	Team presentations	• 15 min in-depth presentation by individual teams
10:45-12:15	Light Metals Market Overview/ Vehicle Light-Weighting – Panel Discussion	• Future of light metals in vehicular applications • NADCA, Timet, DOE loan office
13:15-14:15	Team presentations	15 min in-depth presentation by individual teams
14:30-16:15	Additive Manufacturing – Panel Discussion	• AM opportunities and challenges for light metals • ORNL, America Makes, Boeing, DARPA
16:15-16:30	Wrap-up, Day 1	
16:30-18:30	Poster session/cash bar	• Networking opportunity
18:30-	Dinner (on your own)	

Meeting Agenda – Day 2

	Agenda	Objective
9:00-9:15	Welcome	• Recap of day 1 by the program director
9:15-10:15	Team presentations	• 15 min in-depth presentation by individual teams
10:30-12:00	Scrap Recycling – Panel Discussion	• Industry needs and challenges • OmniSource, Mercury Marine, ISRI
12:00-13:15	Lunch – Scale-up discussion Speakers: Alcoa	
13:15-13:30	Closing remarks	

U.S. DEPARTMENT OF
ENERGY

www.arpa-e.energy.gov

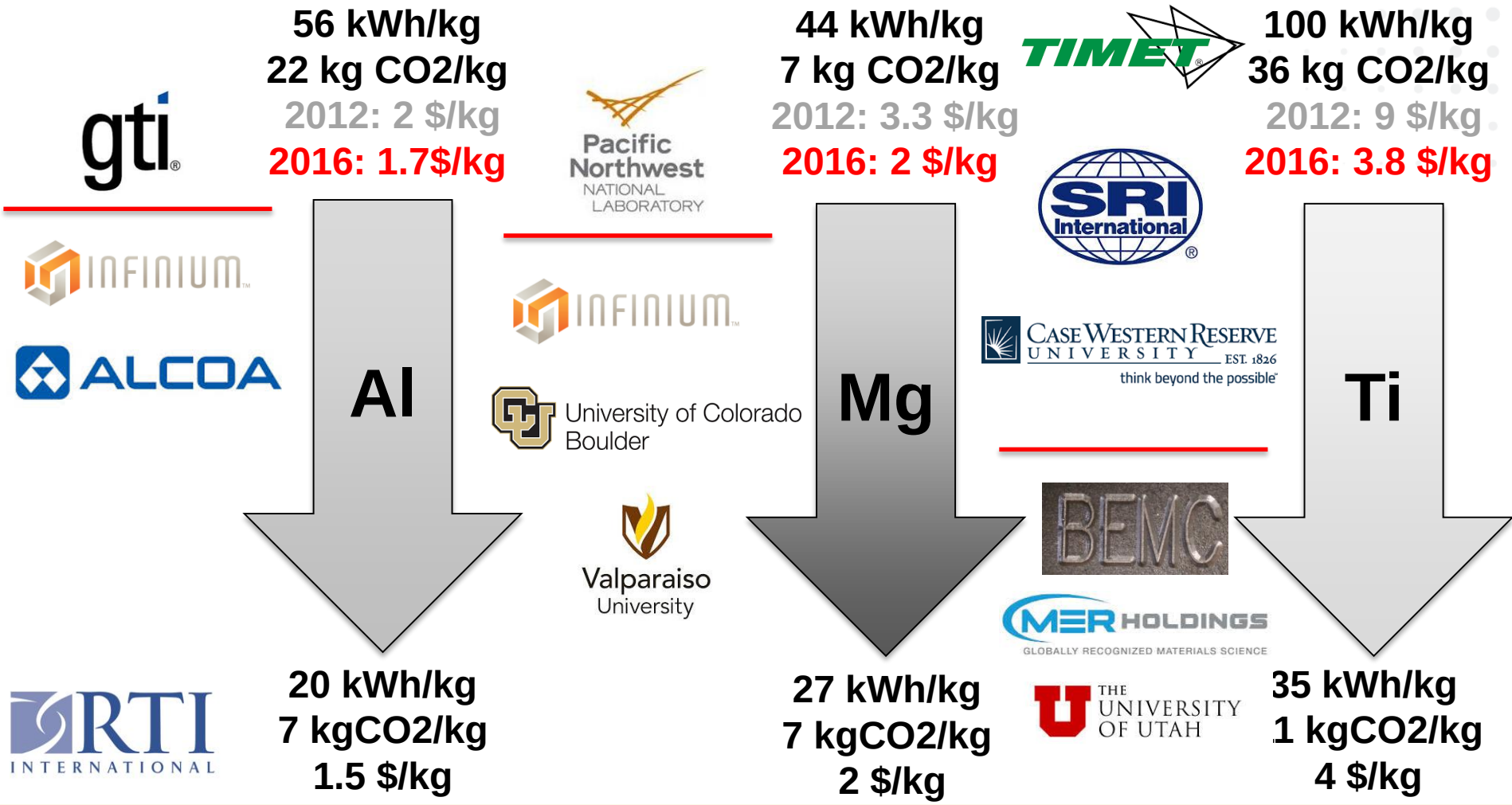
ARPA-E METALS Program

Produce the most energy efficient light metals to enable vehicle lightweighting for energy savings.

Close the loop on vehicle recycling.

ARPA-E METALS Program

Primary Metal Production



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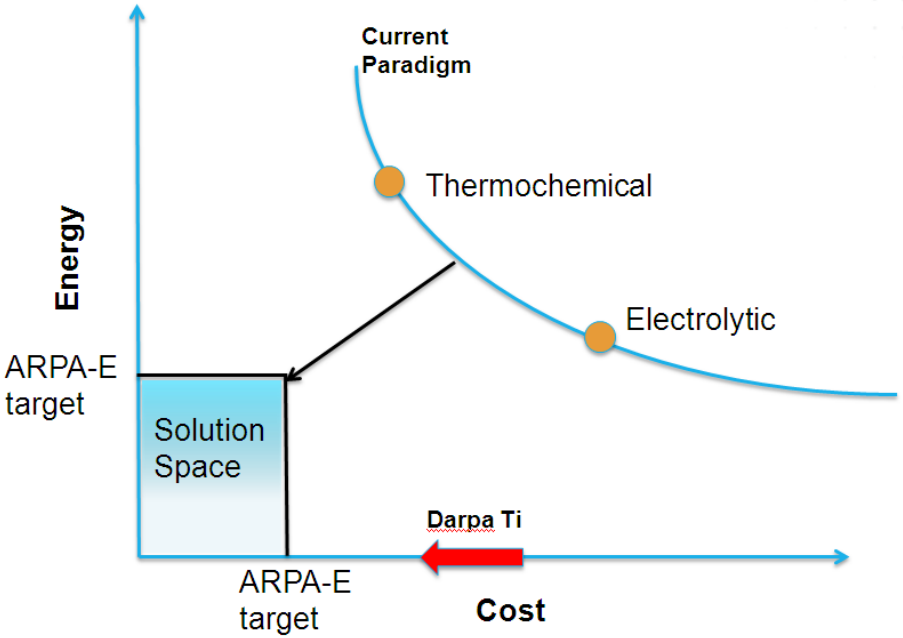
ARPA-E METALS Program: Primary Production

- Light metals enable advanced alternative energy technologies, i.e. lightweight vehicles
- Commercial light metal production processes are energy and emissions intensive
- Domestic light metal production is on the decline due to higher cost of energy, higher cost for labor, and higher cost for importing ore



Thickness Ratio:
SAME part
SAME bending strength
DIFFERENT material
t – thickness
S – yield strength

$$\frac{t_1}{t_2} = \sqrt{\frac{S_2}{S_1}}$$

Scaling Law

$$\frac{C_2}{C_1} = \frac{E_2}{E_1} = \frac{\chi_2}{\chi_1} = \sqrt{\frac{\rho_1 SR_2}{\rho_2 SR_1}}$$

SR – strength to weight ratio
C – cost intensity
E – energy intensity
χ - emissions intensity

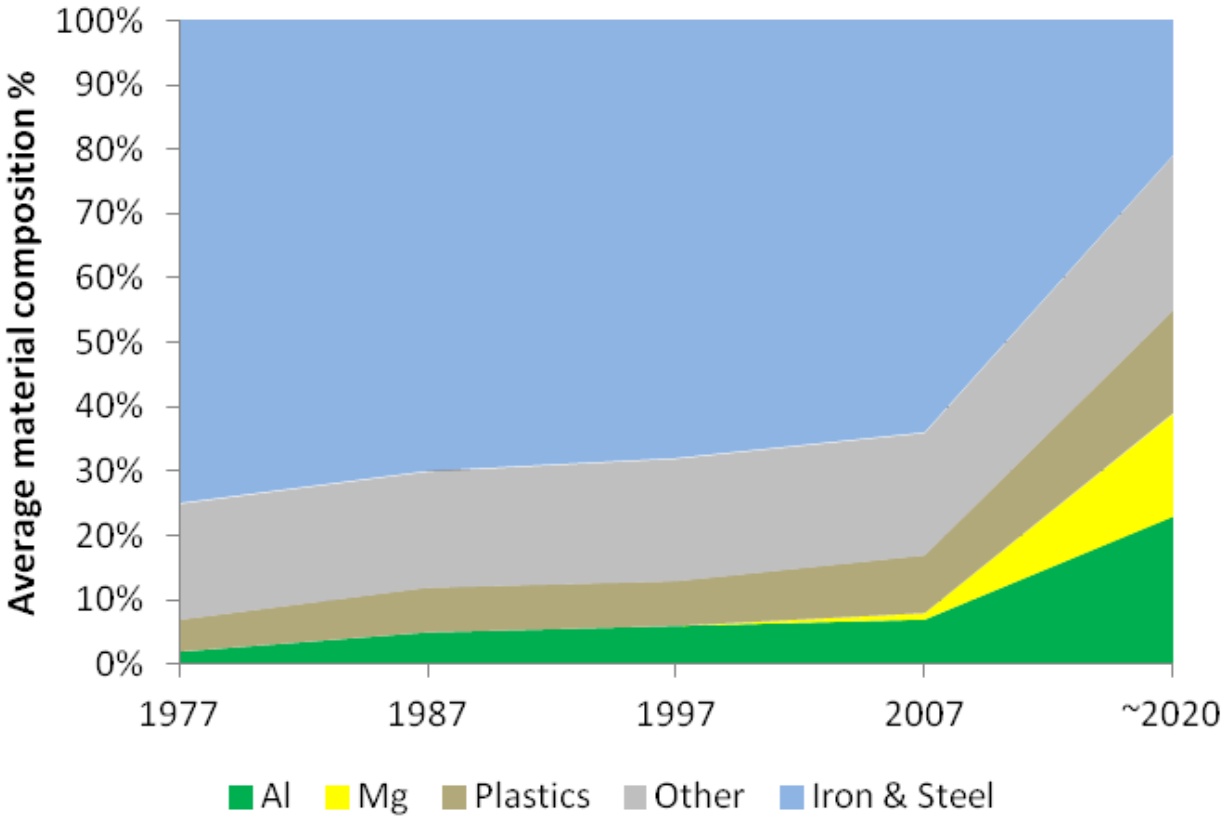
Goal is Al, Mg parity with steel
Ti parity with stainless steel

Significant Increase in Light Metal Deployment for Ground Vehicle Lightweighting

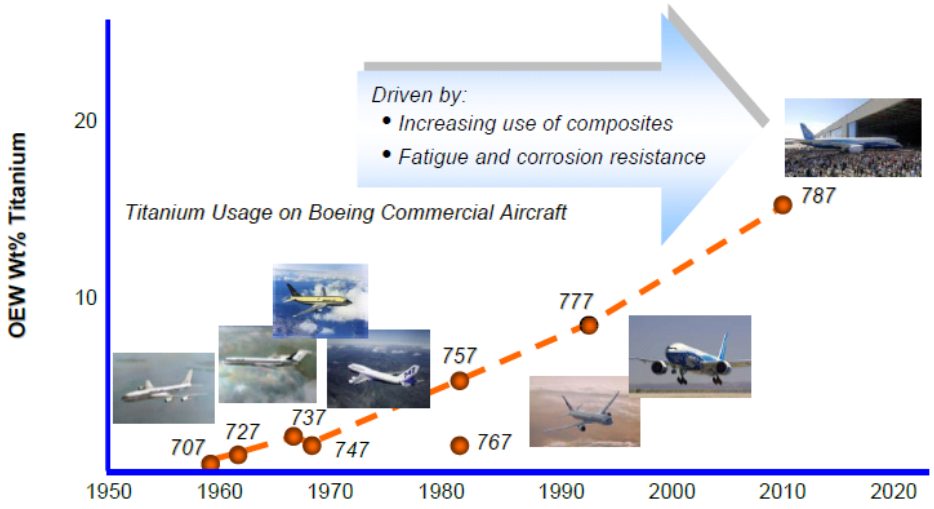
Ford Launches new aluminum body F150 as a production vehicle

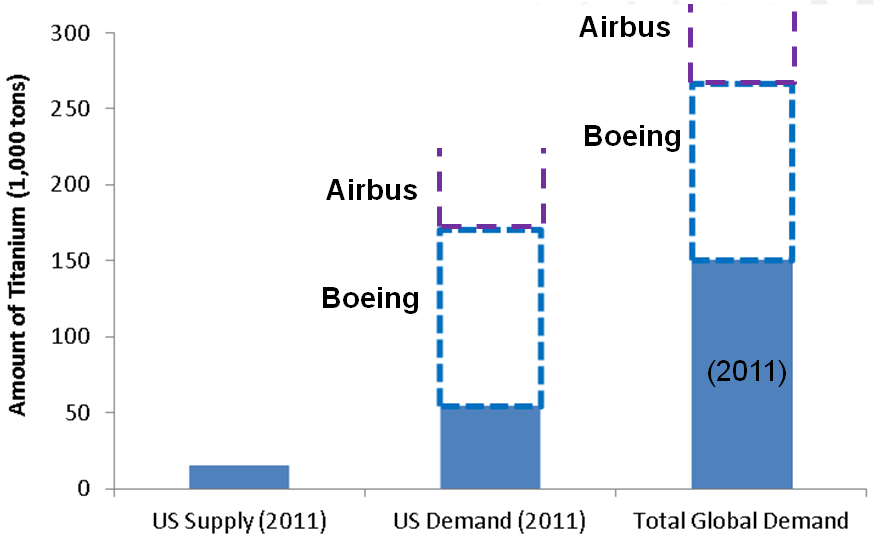
Global demand for aluminum projected to more than double by 2025

Material composition of baseline (1977-2007) and mass reduced (2020) vehicles



Ti Demand Projected to More than Double Due to Aircraft Lightweighting

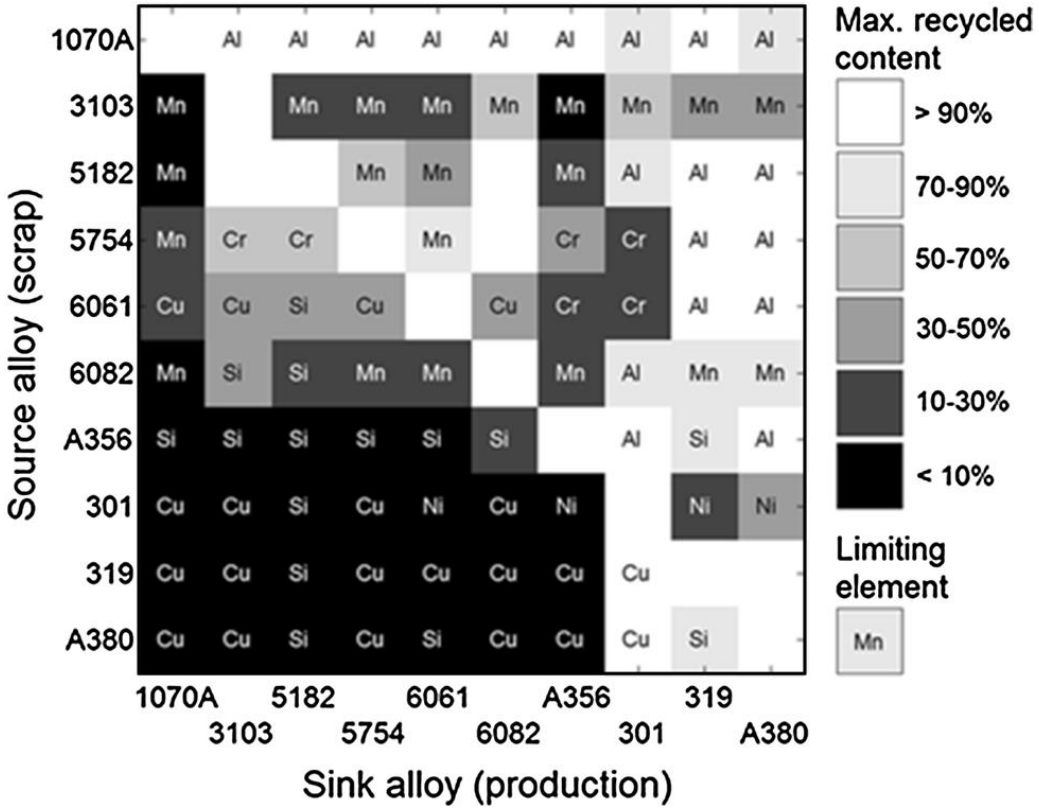


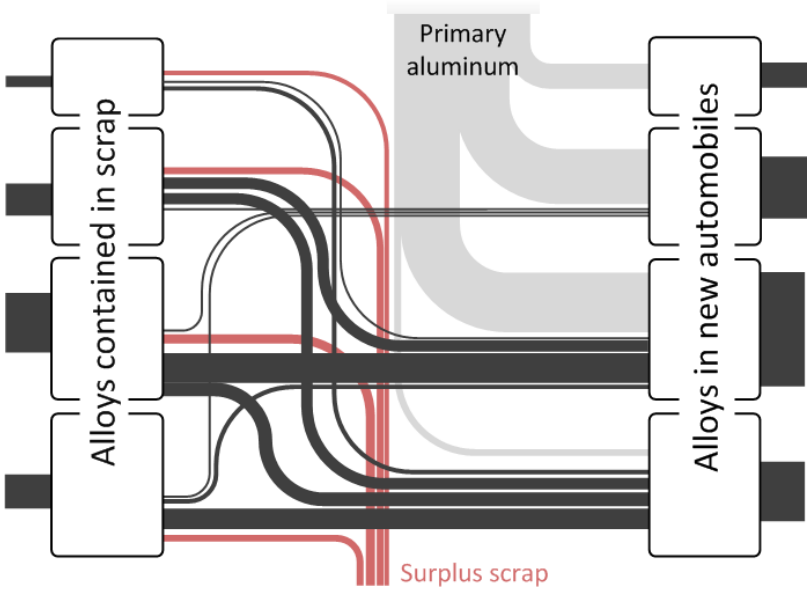


- **Boeing 787 and 777 lightweight aircraft require 80 and 50 metric tons of titanium per airplane, respectively (enabler of carbon fiber)**
- **Boeing projects 34,000 new airplanes to be built between 2012-2031**
- **2.2 million tons required to meet demand or 116 thousand tons/yr**

ARPA-E METALS Program

Elemental Mass Balance on Aluminum Scrap Highlights Need for Advanced Sorting Technologies for Sustainable Recycling

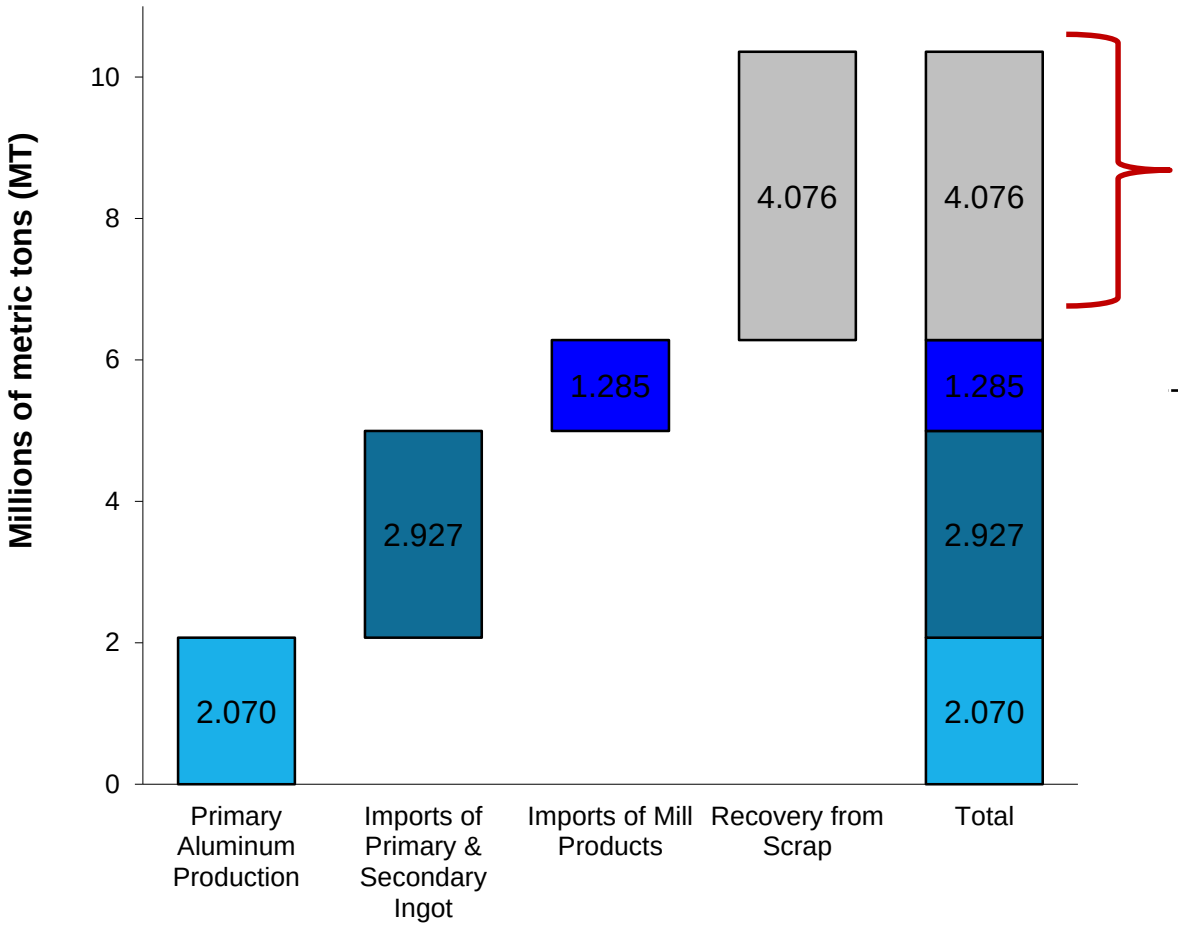




ARPA-E METALS Program

2012 scrap recovery comprised 1/3 of domestic Al supply

Domestic Aluminum Supply (2012) 10.358



US Scrap Recycling (2012)

	(MT)
Scrap Consumption (domestic)	4.076
- Scrap Imports	0.598
+ Scrap Exports	1.984
Apparent Domestic Scrap Recycling	***5.462***

ARPA-E METALS Program

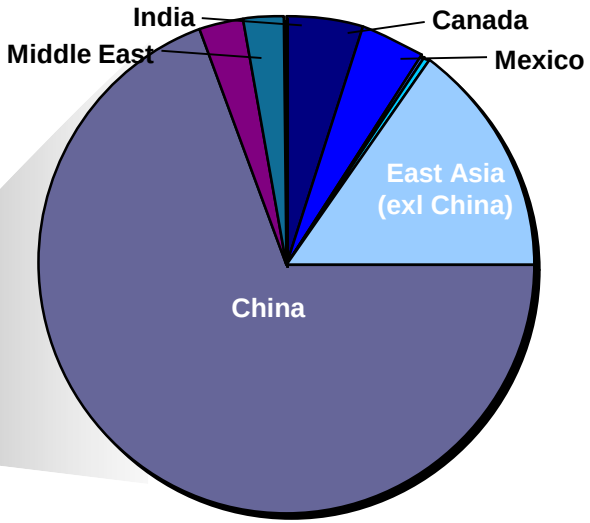
Scrap exports equivalent to 100 TWh of processing energy exported

Aluminum Scrap Domestic Supply and Use (Mtons and GWh, 2012)

(MT)		(GWh Processing Energy)
5.463	Scrap Generated in US	305,957
0.598	Plus Scrap Imported	33,479
6.061	*Total US Scrap Supply*	*339,436*

4.075	*1.984*	*228,280*	***111,130***
MT Consumed Domestically	*MT Scrap Exported*	*GWh Processing Energy Consumed Domestically*	*GWh Processing Energy Exported*

Scrap & Dross Exports (2012)



Comments:

- *111,130 GWh represents ~3% of overall US annual electricity generation*
- *Recycling aluminum consumes only ~8% of the energy of primary production*
- *Exported aluminum scrap is typically blended and downgraded, creating lower priced alloys and thus destroying value*

Note: Numbers do not sum exactly due to rounding

ARPA-E METALS Program

Alloy Composition of Twitch

Series	% in Twitch	$/kg
356	6.9%	$2.31
413	0.4%	$3.15 – 3.35
1050	1.6%	$2.44
1100	0.0%	$2.21
3003	1.4%	$2.29
3004	0.0%	$2.30
3105	0.2%	$2.20
5005	2.4%	$2.39
5052	7.8%	$2.44
6061	10.5%	$2.36
6063	11.8%	$2.24
319	0.1%	$1 – 4
320	10.8%	*
360	4.2%	$3.80
380	17.6%	$2.26
384	6.5%	*
395	15.1%	*
2024	0.1%	$2.41
2025	1.0%	$2.41
2618	0.1%	$2.32
7075	1.5%	$2.32
Weighted Average $/kg		***$2.51***

The "opportunity cost" of shipping scrap overseas is approximately $1,568 million per year

Scrap Export Opportunity Cost

Scrap Exports (2012) (Mtons)	1.984
Average Zorba price (per kg)	$1.72
2012 Export Amount ($ millions)	***$3,412***
Weighted Average $ Value / kg	***$2.51***
"Value" of Exported Alloy	***$4,980***
Opportunity Cost of Alloy Exports ("Value" – Export $ Amount)	***$1,568***

Source: Wrought alloys (XXXX series) from Brent Mydland, Alcoa. Cast alloys (XXX series) from metals pricing websites, Alibaba

** Pricing data not available; for weighted average calculation purposes, $2.72/kg is used for 320, 384 and 395 alloys. $2.72 is the average price of 3XX alloys in table*

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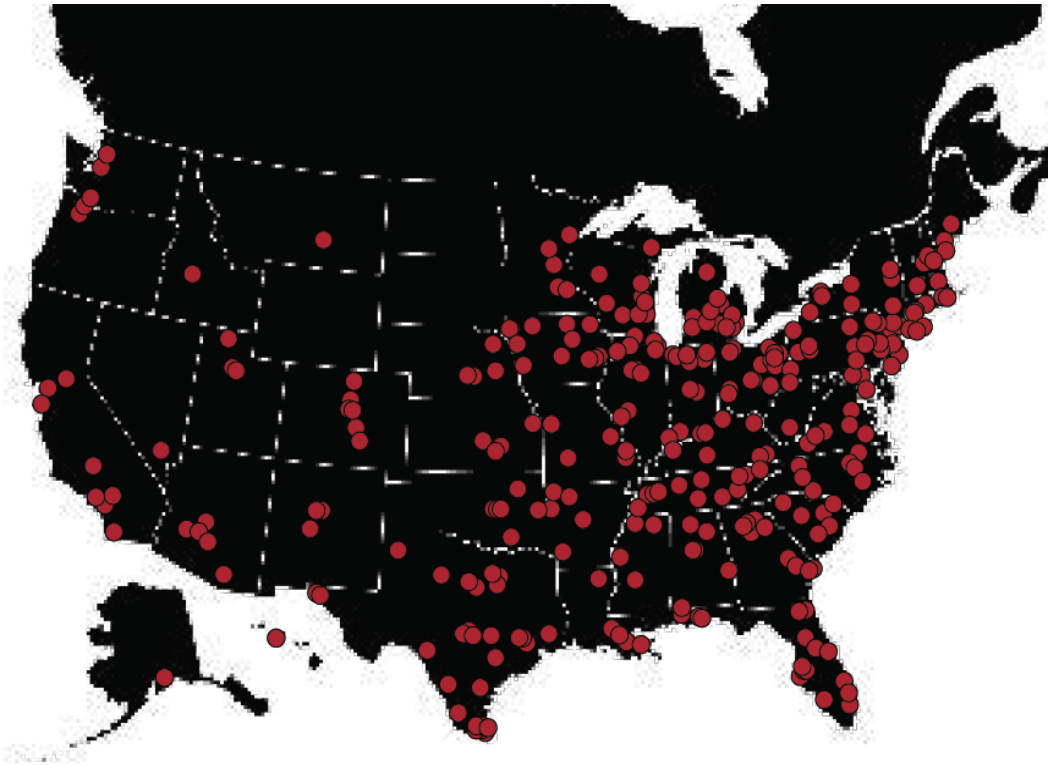
Scrap is typically aggregated for export at scrap yards with shredding facilities - approximately 300 locations in the US

US Auto Shredder Locations



High Level Market Size for Diagnostic Equipment

Total Shredders	300
Assume 10% adoption/year	10%
Annual Diagnostic Installations	30
Assume Diagnostic Capital Cost	$5M - $10M
Approximate Annual Market Size for Diagnostic Equipment	***$150M - $300M***

An alternate business model is for performers to purchase unsorted scrap, perform sorting, and sell sorted metal – ERCo's AIM product will likely use this method as a first market

Source: Map from US Shredder.com

METALS ARPA-E Team

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